Reducing Energy Use in Low Power Modes: Research Directions*

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Introduction

Low power modes[2] exist in an impressively diverse collection of products: from desktop computers to ceiling fans and from washing machines to set-top boxes. This diversity is also reflected in the kinds of research needed to conserve power in those modes. This section summarizes key strategies to reduce energy use in low power modes. Finally, we recommend several areas for future research. One of the themes that runs through the research activities is the need to lower costs, increase reliability, or to transfer an idea that has been proven in prototypes to something that can be mass produced.

Government Sponsored and Corporate Research

We are aware of only one government-sponsored research program to reduce low power modes. In the late 1990s, the Japanese government encouraged companies to investigate technologies to reduce standby by sponsoring several million dollars of research. Unfortunately, there are no formal reports from this work. While targeted research may be rare, research on other topics may also benefit technologies for low power modes. Certainly many of the low power solutions devised for battery-powered, portable products have potential application in stationary products (if the cost can be reduced). Another example is the research sponsored by the Defense Advanced Research Projects Agency (DARPA) to improve communications sensor arrays and to develop low-power microprocessors has potential applications to reducing low power modes.

We are confident that many companies are undertaking private research to improve efficiency of low power modes. Unfortunately, most of this research is proprietary (until it is released in a product).

Efficiency Strategies

In spite of the diversity of products, there are three general approaches to reducing standby and low power modes. These are listed below:

- Hardware improvements that generally improve the energy efficiency of components
- Software improvements that better match the equipment operation with functional needs
- External improvements that allow or encourage more efficient operation

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[2] In this paper we refer to three basic operating modes: On, Sleep, and Off. Low-power refers to the combination of Sleep and Off. Previous LBNL papers have used Low-power as a synonym for Sleep. The term "Standby" is now generally being recognized as a power level and not an operating mode. Most devices achieve their standby power use when Off, so we sometimes use Standby to refer to the Off mode.

Many products will be improved by more than one of these approaches. For each of these major strategies, we explain the principal technical problem, past developments, and fruitful areas of future research. Finally, we recommend several areas for future research.

Hardware Improvements

Standby power generally exists when one or more of the following technical features is present in a device:

- An external power supply
- Continuously operating sensor, display, or input/output device (including receiver for a remote control)
- Internal clock
- Rechargeable battery

Other low power modes may involve use of a microprocessor to perform relatively low-level functions (compared to what it does during active modes).

For each of these features, with widely varying power requirements, there are often several different technologies available or under development. Some offer greatly reduced power consumption while providing the same services. Examples are listed below.

Increase the Efficiency of the Power Supply and Circuitry

A recent analysis (Calwell and Reeder 2002) estimated that at least 6% of the nation's electricity flows through low-voltage DC power supplies, of which about one was consumed while the products were in standby or sleep modes. All of the low-power modes—at least in this project—are caused by operation of electronic components. Most of these components require low voltage (usually less than 12 volts) Direct Current (DC) power. As a result, a power supply (or "transformer") is needed to convert mains electricity (at 100 – 250 Volts AC) to lower voltage direct current. The process of converting the high voltage electricity to the desired form incurs losses. A "no load" loss occurs whenever the power supply is energized but supplying no power to the device. There are further inefficiencies in conversion. The conversion efficiency varies with the load; it is typically least at part load and highest as it approaches the designed capacity.

The no-load power loss is the minimum power consumption of all products with separable, external power supplies (often called "bricks", "cubes", "vampires", "wall warts", etc.) when they are plugged into an outlet but not into the product itself.[3]

There are two main paths to improve the efficiency of the power supply. The first involves isolating the low power circuits and energizing them through a separate power supply. This strategy succeeds because the power supply can then be sized to the specific power demands of the low-power modes, so it is usually more efficient in all aspects. It also allows the primary power supply to be better matched with power requirements while in the active modes.

A second strategy is to change the technology of the power supply (primary or auxiliary). Most research and development has been directed to a shift from analog, linear power supplies, to digital, switching power supplies (Calwell and Reeder 2002). (This approach applies to both

[3] Manufacturers have strong incentives to use external power supplies. By moving the power supply outside the product and feeding it low voltage power, the manufacturer avoids expensive safety and testing requirements (such as UL listing). The power supply is also a heat source, so moving it outside simplifies design of the consumer product. If the product will be used in different countries, then the power supply must be changed to match the local voltage and frequency. This is easily accomplished with external power supplies.

internal and external power supplies.) An example of the family of switch mode power supply solutions are those offered by the California firm, Power Integrations (http://www.powerint.com). Originally this type of power supply was only available at very low power levels (up to a few watts). Maximum capacity has been rapidly increasing, along with efficiency over the whole range. Power solutions with no-load losses of less than 0.1 W are now available. Switch mode power supplies are now available up to over 100 W, though losses are higher. See Table 1 for specifications of typical products.

Table 1. Performance specifications for high-efficiency switch mode power supplies (source: Power Integrations).

Application	Output		P_{out} @1 W Input (W)	P_{in} @No-Load (W)
Home Appliance	1.2 W	12 V	0.7	0.05
AC Adapter	3 W	9V	0.7	0.09
Digital Modem	10 W	3.3 V, 5 V, 30 V	0.39	0.34
PC Standby	10 W	5 V	0.77	0.06
Set Top Box	43 W	3.3 V, 5 V, 12 V, 18 V	0.13	0.7
AC Adapter	70 W	19 V	0.5	0.35

Other companies offer similar power solutions, including ON Semiconductor, Astec, and Bias. The original driving force behind development of switch mode power supplies was not energy efficiency but other factors, such as minimizing heat gain, reduced inventory, and lower weight. The major research challenges are to increase capacity while not sacrificing cost and efficiency (especially at part load). Note that improvements in power supply efficiency are also likely to save power during active modes; indeed, the energy savings may actually be greater during the active modes depending on the product’s configuration and pattern of use.

Some appliances–such as many halogen desk lamps and LCD displays with external power supplies–have switches on the low-voltage side of the power supply. Even when the user has switched off the device, the power supply remains energized and continues to draw power (no-load loss). One strategy to reduce no-load losses is to move the power switch to the high voltage side of the power supply. Note that a high voltage switch costs more than a low voltage switch, so the manufacturer only sees an increase in cost. Other soft-switching approaches may be feasible but there has been little exploration of these options.

The major research agenda for power supplies is increasing efficiency (at all loads) while lowering costs. These goals are technically challenging because other design aspects, such as power quality and electro-magnetic interference, need to be maintained or even upgraded. Since so much of the nation’s power eventually passes through power supplies, the benefits will certain extend beyond energy savings in low power modes.

Reduce Power Draw of Circuitry

There also exists considerable potential to reduce power draw of circuitry while in low power modes. The first step is simply to re-design circuits to entirely de-energize components that are not needed while in this mode. In the case of working specifically with the Intel chipsets—a common situation—at least one book (Kolinski et al. 2001) is exclusively devoted to power efficient PC design. Clearly experience from portable electronic devices like PDAs may be applicable. More general approaches to reducing the power draw of circuits are available.

(Rabaey and Pedram 1995) and prototypes of circuits requiring a hundredth or thousandth of the power of present circuits are underway at several laboratories around the world.

An increasing number of devices drawing standby power are permanently connected (“hardwired”) into building electrical systems. Some of the most common devices are smoke and fire alarms, GFCI outlets, emergency lighting and exit lights. Smoke detectors were once powered by batteries–many still are in existing buildings–but but conversion to line voltage raised their power consumption several hundred-fold. Opportunities to reduce their energy use have not been systematically examined. A unique research aspect is lowering power use without compromising safety.

Increase Efficiency of I/O Components

A wide array of components addressing input and output needs may be energized while products are in low power modes. Some of the most common of these and their function are listed in Table 2.

Table 2. Common components and their purpose during low power operation

Component	**Example of Function**
Indicator light	Indicates device’s status
Display screen	Displays information, time, or status
Telephone line sensor	Detects incoming telephone/fax message
Energized touchpad	Waits for user input (such as on a microwave oven)
Network sensor	Detects network activity for computer to receive wake-up signals
IR sensor	Detects IR signal from remote control
Temperature sensor	Thermostat controls
Ambient light detector	Controls outdoor lighting

Most sensors already consume very little power, on the order of milliwatts. Recent research (http://www.citris.berkeley.edu/) has demonstrated that sensors drawing nanowatts are feasible. Complex networks of these sensors can be created with power draws in the microwatt range. Berkeley researchers have also developed a miniature operating system to coordinate the networks. At this level, entirely new approaches to sensing, communicating, and controlling information are possible, as well as the power sources needed to run them. One idea, for example, is to harness ambient air currents and illumination to power the circuits.

Displays and indicator lights need to be sufficiently bright so as to be visible even in bright conditions. Furthermore, the displays and indicator lights must tolerate the range of expected temperatures and other conditions. Displays for ovens, for example, need to withstand high temperatures and, to some extent, have dictated the type of displays used. Indicator lights—such as those used to indicate the status of computer monitor—consume small fractions of a watt. Traditional displays for small appliances (like microwave ovens, dishwashers and office equipment) rely on various technologies and draw anywhere from a fraction of a watt to several watts. The Bose audio line’s principal obstacle to reducing standby to below one watt was its displays.

Agilent and Philips recently developed several, high efficiency, LED lighting sources. These lights provide a satisfactory color range, brightness, along with extremely high efficiency. An Agilent spin-off, Lumileds (http://www.lumileds.com), has pioneered a wide range of bright lights under 0.23 W with efficacies approaching that of fluorescent lights many times larger (Haitz et al. 1999). Other technologies are also being investigated, notably, organic LEDs (OLEDs).

Dimming a display is also an option. One feature of many new displays is their ability to adjust brightness (hence, power draw). The display's brightness could be controlled by either an ambient light sensor or an occupancy sensor, thus permitting even lower power levels when not required.

Software Improvements

Software—and in particular, Power Management software—helps determine which components are energized during low power modes. It is easy to overlook potential applications of power management, especially in the haste to get a product to the market. For example, we observed a web-TV box whose hardware included chips capable of power management but the designers failed to enable it. Simply enabling the existing power management capability would have cut the box's power use by several watts. Full exploitation of power management is challenging and requires extensive knowledge of the microprocessor's capabilities (Kolinski, Chary et al. 2001).

Software also determines when a device should switch from an active mode into a low power mode. Clever software designs may actually increase the time a device is in a low power mode but save energy overall because they reduce the time the device is in active mode. In this way, software can save more energy than is presently used in a device's low power modes. The web TV example above illustrates the potential savings. The original design lacked any low-power mode, but enabling the power management would have created a low power mode.

In other situations the software will need to be rewritten to create lower power modes. For example, we observed a set-top box that kept video digitization chips energized even when there was no video input and no requests for it.

External Changes

The strategies to raise the efficiency of low power modes described above deal with changes inside the device. Another group of measures apply to the external conditions that will lead to, or at least permit, lower energy consumption. We describe three possible measures here.

Improved Communication Protocols

Set-top boxes and other devices connected to a network must be sufficiently awake to detect a signal. Details of the communications protocol will determine the level of device "awakeness" and the resulting energy use. Many cable service providers rely on crude communications protocols that require the box to remain fully awake at all times. Some of these cable boxes remain fully awake—and drawing over 20 W –waiting for once-daily interrogation from the service provider.

Improved communications protocols would allow the network device to enter a low power mode until the service provider actually needs information. Small changes, such as installing an auxiliary signal sensor chip, and allowing time for the box to return to an active state, will greatly increase the proportion of time in which the box can remain in a low power mode. Wireless communications protocols, such as Bluetooth, already provide for states which require less interaction and power. In these low power states, circuitry pays only as much attention as it needs to know when to wake up.

A Building-Wide DC Power Network

Commercial buildings have a wide range of devices operating on DC power, including most office equipment (except copiers), exit signs, emergency lighting units, and elevators. Buildings of the future will probably be illuminated by by LEDs, which also rely on DC power. In most cases, each device has its own power supply to make the conversion. Note that many Uninterruptible Power Supplies (UPS) convert AC into DC, create AC, and then feed it to equipment that converts it again to DC. Clearly AC-DC conversion losses will be significant, even when the equipment is in sleep mode.

One technology that would potentially reduce standby power is the establishment of a building-wide DC network. Such a network could, in principle, eliminate a greater part of conversion losses. There are significant technical limitations but telco buildings have long used DC networks and designers of data centers are considering separate DC feeds. These buildings have large banks of servers where heat removal is major technical challenge; removing the power supplies allows closer stacking and lower heat densities in critical areas (and removes power supplies as a point of failure). Some routers and switchers are now available in both AC and DC input configurations.

DC networks have been around since Edison's time, but the research challenge is to make them cheaper and more efficient.

Improved User Interface

An ongoing problem for energy savings of office equipment is the large portion of devices that have the capability to power manage, but have the feature disabled, or enabled less than optimally. Part of this can be attributed to the user interface for power controls being hidden, absent, or confusing. Making the user interface for future products easier to understand, and most importantly consistent from device to device, is usually a no-cost way to facilitate energy savings.

The CEC, through PIER, has funded an effort to define a set of voluntary user interface standards for power controls. More can be found on that at: http://eetd.LBL.gov/Controls. While this provides an important foundation, there is additional work that can be done to gain the most from this: follow the process of making the standards a U.S. national standard, and then an international standard; actively market the standards to manufacturers; deepen them in specific product areas such as display dimming, multiple monitors, and responsiveness to real-time price controls. In addition, areas with emerging low-power loads, such as lighting, may benefit from user interface standardization.

Research Recommendations

- Develop communications protocols for networks to accommodate the lowest possible power modes while not in active. Two important networks needing immediate attention are the cable television networks (service provider's relationship to the consumer's set-top box) and home networks (which will eventually include white goods and other appliances).
- Improve power supply efficiency, especially at part loads

- Improve energy management, possibly with more modes
- Develop dimmable displays linked to information from sensors
- Explore viability of DC networks for commercial and residential situations
- Investigate technologies to reduce standby in “hardwired” devices
- Standardize user interfaces to encourage greater reliance on low power modes
- Optimize battery charging circuitry
- Long-term: explore ultra low-power circuitry and ways to supply power to it

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